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THE VERIFICATION OF A COMPUTER MODEL OF INTERNAL LIGHT REFLECTIONS FOR HELICOPTER CANOPY DESIGN

Christopher C. Smyth
Harry R. Stowell

October 1979
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U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland

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The US Army Human Engineering Laboratory (USAHEL) has experimentally verified a computer model for internal light reflections on the transparent surfaces of helicopter canopies. The model was verified using a mockup of the Model 209 AH-1S Helicopter with the flat plate canopy design. The transmittance and coordinates of the light images on the canopy surfaces were measured at various light source positions. A matched sample was computed for the source positions using the computer

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20. ABSTRACT (Continued)

model. Pearson's correlation coefficients for a linear regression analysis of the matched measured and computed values are greater than 0.98, and the results are statistically significant at the .01 level.

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CONTENTS

THE VERIFICATION OF A COMPUTER MODEL OF INTERNAL LIGHT REFLECTIONS FOR HELICOPTER CANOPY DESIGN

INTRODUCTION

The US Army Human Engineering Laboratory (USAHEL) has developed several computer programs for evaluating helicopter canopy designs. The programs provide a point-wise computation of the internal glare reflections, external solar glint and the optical effectiveness of the transparent surfaces of a helicopter canopy design. The programs were developed using geometrical ray tracing methods.

The purpose of this report is to verify the application of ray tracing concepts to the computation of canopy performance. The report describes the method used to test a computer model for the internal light reflections on the transparent surfaces of a helicopter canopy and the test results.

METHOD

A mockup of the Model 209 AH-1S Helicopter, flat plate canopy design, was placed in the enclosed bay of a building. A coordinate reference system was laid out on the floor about the mockup. An observer sitting in the pilot's position of the mockup used a pointer to pinpoint the locations of direct view and reflected images, on the canopy surfaces, of an outside light source. In the first phase of this test, the luminances of the images were measured with a telephotometer. In the second phase, the coordinates of the locations of the images on the canopy surface were measured. The data were measured at different positions of the light source on the outside floor. The source positions were different for the two phases.

The transmittance and coordinates of the image locations were computed for the different light source positions using a computer program. The measured and computed values were compared by a student's t-test for matched samples and by a linear regression analysis.

TEST FACILITIES

The helicopter mockup was supplied to USAHEL by the Project Manager's Office, USA Aircraft Survivability Equipment (ASE). The mockup had been built in accordance with the specifications for the Model 209 AH-1S Helicopter, flat plate canopy design. The mockup was placed in an enclosed bay area for the test. The room was sealed for light control and the walls

and ceiling were painted with a flatbase black paint to prevent extraneous reflections. The two ceiling lights were shielded to prevent direct glare and the lights were dimmed during the test.

A brow pad was installed in the cockpit of the mockup at the pilot's position. The pad extended vertically downward from the top canopy surface and was positioned so that the eyes of an observer, sitting in the pilot's seat, would be in the nominal position when his brow was against the pad.

A rectangular (x,y) coordinate system was laid out on the bay area floor for positioning the light source during the test. The origin of the coordinate system was positioned directly under the nose of the mockup with a plumb bob. The y axis was laid out directly beneath the centerline of the mockup parallel to its longitudinal axis. The x axis was laid out normal to the y axis. The x and y axes were marked in 1-foot intervals for use when positioning the light source during the test.

A 5-foot stand was built with a movable clamp to hold the 1.5-inch diameter light bulb. The stand could be moved to any position on the bay floor. The clamp holding the light bulb to the stand could be raised or lowered to any height up to 5 feet above the floor level. The stand and the light bulb served as the light source for the test.

Apparatus

The apparatus employed in this test were used to measure (1) light luminance, (2) the coordinates of the canopy surface points, and (3) the coordinates of the vertices of the mockup frame. The apparatus and their usage are as follows:

1. Light Luminance

a. The luminance of the light source images on the canopy surfaces was measured with a telephotometer with the following components: Model 220-31 photometric telescope (aperture setting, 20 minutes), Model 820A digital photometer, Model 820-18 control module, Model 820-18 photopic correction filter, Model 820-18-2(S4) photosurface tube, Model 820-19 general-purpose housing, and Model 700-3B fiber optics probe (Gamma Scientific Co., Burbank, CA). The instrument error is 5 percent.

b. The telescope was focused and centered on the image of the light source by the observer who was sitting in the pilot's seat. The luminance was read from the digital meter and recorded by an assistant while the observer kept the telescope centered on the image.

c. The luminance of the 1-1/2-inch diameter light source was measured from outside the mockup. This direct line of sight measurement served as a baseline for transmittance computations and was rechecked during the test.

2. Coordinates of Canopy Surface Points

The three-dimensional Cartesian coordinates of the light source on the canopy surfaces were measured using a plumb bob, a level and a tape measure. The observer sitting in the pilot's seat used an expandable metal pole during the test to pinpoint the location of the light image on the canopy surface. The position was marked with a small tab of adhesive tape. The distances separating the image position from a convenient vertex on the mockup frame were measured using the level, the plumb bob, and the tape measure. The coordinates of the image position are the distances along the three-dimensional axes of the Cartesian coordinate system for the mockup, which separate the image from the vertex.

3. Coordinates of the Vertices of the Mockup Frame

a. The coordinates of the vertices of the mockup's internal structure and canopy frame were measured using a surveyor's transit theodolite (Keuffel and Esser Co., Hoboken, NJ). The internal structure included the copilot's seat, gun sight and display panel, and the pilot's side armor and control panel. The canopy frame included the beam structure over the cockpit which held the transparent surfaces in place.

b. The coordinates of these vertices were measured in the three-dimensional (x,y,z) coordinate system of the mockup. The y axis was along the longitudinal axis of the mockup with the positive direction toward the increasing station lines. The z axis was the vertical axis directed along increasing water marks. The x axis was orthogonal to the other two axes.

c. The coordinates were measured using the theodolite, a steel rod and a tape measure. The theodolite was positioned in front of the mockup and two reference directions were laid out on the bay area floor. One direction was along the longitudinal y axis of the mockup, and the other orthogonal to it (x axis). The theodolite was then lined up with the appropriate axis for the coordinate to be measured; i.e., along the y axis for the x coordinate values, along the x axis for the y coordinate values, and leveled with the horizon for the z coordinate values. The coordinate values were measured by placing the point of the rod at the vertex being measured. The rod was aligned with the coordinate axis using the crosslines of the theodolite. The distance along the rod from the vertex to where the crosslines crossed the image of the rod was measured as the coordinate value.

Observer

The test is of a mathematical model for light reflections and no subjects were employed. The single observer was one of the data collectors for the test. His ability to place a pointer at the position where he observed a light image on a surface was not considered to be a test variable.

Procedure

The test was divided into two phases. In the first phase, the luminance was measured for all direct view and reflected light images. In the second phase, the coordinates of the canopy surface positions were measured for the direct view and reflected light images. The two phases used different sets of light source positions.

A set of 15 test positions was selected at random for the light source used in each test phase. The set was selected from a larger set balanced with respect to floor location and stand height about the mockup. The set was also balanced, as much as possible, with respect to the windows and canopy surface locations where reflections were expected to occur. The test set was randomly ordered for presentation to the test observer.

The light source was presented to the test observer from the selected test positions in a series of test runs. The test assistant positioned the light source at the floor location and stand height specified for the test run. The stand was located on the floor by tape measurements from the previously laid out coordinate axes (see Test Facilities). The stand height was measured from the floor level. The overhead lights were then dimmed to start the test run.

The observer sat in the pilot's seat with his forehead positioned against the brow pad. He searched for light images on the canopy surfaces. The observer located three types of light images. The first was a direct view of the light source through the canopy. The second type was a primary order reflection in which the light image was reflected once from the surface before reaching the observer's eye. The third type was higher order reflections in which the light image was reflected more than once before reaching the observer's eye. The higher order reflections were distinguished from the primary orders by their movement when other canopy windows were disturbed.

The type of data collected at the end of each test run was determined by the particular test phase. For the first phase, the observer focused the telephotometer and centered it on the light image while the assistant recorded the luminance value. This was repeated for each of the located light images in turn.

For the second phase, the observer used a metal pointer to pinpoint the location of the light image on the canopy surface. The assistant marked the position with a small tab of adhesive tape. He then measured and recorded the distances between the image point and a convenient canopy frame vertex. The distances were measured along the coordinate axes of the mockup. This was repeated for each of the located images in turn.

RESULTS

The reduction of the data for the luminance and coordinates of the test light images, computation of a matched sample by computer program using the mathematical model for light reflections, and the statistical analyses of the matched sample of measured and computed values are discussed below.

1. Data Reduction

a. The transmittance values of the light source were calculated for the image points of the first test phase data. The transmittance values equal the luminance readings of the light images divided by the luminance reading of the light source.

b. The three-dimensional coordinates of the imag surface points in the mockup coordinate system were calculated for the second phase test data. The coordinates of the image points equal the sum of the coordinates of the appropriate vertex and the corresponding displacement distances which were measured for the image points. The coordinates of the frame vertices were measured separately using a surveyor's level (see Apparatus).

2. Computation of a Matching Sample

a. A computer program (see Appendix C) was written to compute the transmittance values and coordinates of the images on the canopy surface of a light source. The program was developed using ray tracing concepts (see Appendix B) and is applicable to direct view and primary order reflections.

b. The input data to the program are (1) the canopy frame data, (2) the location of the mockup on the bay-area floor, and (3) the location of the test lights on the floor. The coordinates of the vertices of the frame and canopy surfaces are program input data. The vertice coordinates were measured after the test using a surveyor's level (see Apparatus). The coordinates of the origin of the mockup's coordinate system, measured in the rectangular coordinate system on the bay-area floor (see Methods), are program input data. The orientation of the mockup's coordinate system, as measured from the floor system, is also input to the program. Finally, the floor system coordinates of the light source positions in the test are read by the program.

c. The program computes the transmittance value and the coordinates of the direct view and reflected image points on the canopy surfaces for each light source position. The computations are done for both eyes of the observer, one to the right and the other to the left of the pilot's nominal eye position. The image point coordinates are computed in the coordinate system of the mockup. The printout of computed image point transmittance and coordinates for each of the light source test positions is a matching sample to the values measured in the mockup test (see Methods).

d. The measured and computed values for the image-point transmittance and coordinates are listed in Table 1A for the light source test positions (see Appendix A). The table shows that the coordinates computed for the right eye vision are slightly closer in value to the measured values. This is in agreement with the fact that the observer is right eye dominant. The right eye set of data was chosen as the matching sample.

e. The table lists two computed image points that were not observed in the test and two observed values that were not computed. A physical check of the mockup and the light source locations for these unmatched light images showed that they were caused by slight discrepancies between the mockup and the frame input data. These discrepancies are listed in the next paragraph. The unmatched images were dropped from the samples leaving two balanced and matching samples.

f. The unmatched images dropped from the samples and the reasons for their occurrances are as follows:

(1) A computed image point that was in actuality blocked from the observer's view by the brow pad which was not included in the frame input data.

(2) A computed image point that was blocked from view by two overlapping canopy frame edges that were represented as slightly separated.

(3) An observed image point which occurred at the edge of the canopy surface and which showed a portion of the 1-1/2-inch diameter test bulb, but which was not computed for the point light source assumed in the model.

(4) An observed image point which did not occur in the computations because the mockup nose was assumed to be 2 inches longer than it actually was, and the light source was placed near the nose.

3. Statistical Analyses

The difference score for the transmittance and the three coordinates (x,y,z) were treated in a students' t-test for matched samples (Welkowitz [6], p.142-143). The difference scores were calculated by subtracting the measured values from the computed values for the matching image points of a given light source position (see Appendix A). The main difference scores ($\overline{D}$), the standard deviation (s_D) of the difference scores and the corresponding t-values (t_D) are listed in Table 1. The t-values were calculated by dividing the mean difference scores by the standard error of the mean. The null hypothesis is that the mean of the difference scores is zero. The degrees of freedom (df) for the number of sample pairs are listed along with the corresponding critical t-values (t_c) at the .05 level of significance for a two-tailed test (6, Table c, p. 257). The dimension of the transmission value is in fractional parts and that of the coordinate value is in inches.

TABLE 1

Student's t-Test for Matched Samples

Variable	$\overline{D}$	s_D	t_D	df	t_c*
transmittance	.0112	.0471	.8257	11	2.228
x-coordinate	-.6378	.9769	-2.9197	19	2.093
y-coordinate	-.6940	1.4163	-2.1914	19	2.093
z-coordinate	1.6190	1.1491	6.3009	19	2.093

*.05 level of significance for a two-tailed test.

A comparison of the t-values listed in Table 1 for the scores, with the critical t-values, shows that there is not sufficient reason to reject the hypothesis that the measured and computed transmittance values are the same. However, the hypothesis that the measured and computed coordinate values are not different must be rejected at least at the .05 level of significance (see Discussion).

The matched data for the transmittance and the three coordinates were treated in linear regression analyses (6, p. 152-170). Table 2 lists the Pearson's correlation coefficients (r) for the matched data, the degrees of freedom (df) given by df=N-2 where N is the number of matched data, and the corresponding critical r-value (r_c) at the .01 level of significance for a two tailed test (6, Table D, p. 258). The table also lists the slope (b) and intercept (a) of the linear regression lines and the corresponding standard errors of estimate (s_e). The coefficients of the linear regression line were computed using the method of least squares.

The correlation coefficients listed in Table 2 are nearly equal to unity. A comparison of the coefficients with the critical values shows that the coefficients are statistically significant from zero at the .01 level. The matched data are linearly related in the statistical sense.

DISCUSSION

It was shown in the results that the mean difference scores listed in Table 1 for the x-, y-, and z-coordinates are statistically significant from zero. The mean difference scores are equal to the differences between the sample means for the measured and computed coordinates. The mean differences may be the errors for centering and aligning the coordinate

TABLE 2

Linear Regression Analysis for the Match Data

Variable	r	df	r_c*	b	a	s_e
transmittance	.9923	10	.708	.9476	.009	.0444
x-coordinate	.9985	18	.561	.9145	.3561	.9228
y-coordinate	.9973	18	.561	.9987	.8385	1.380
z-coordinate	.9897	18	.561	1.0981	-10.655	1.149

*.01 level of significance for a two-tailed test.

system of the test-area floor with that of the mockup. The centering was done by plumb bob and the alignment by tape measure and line of sight. The height of the mockup's top canopy surface above the test area floor was measured by tape sometime after the test. The intervening period was used by other personnel to measure the coordinates of the vertices of the mockup frame. The mockup was inadvertently braced during the operation thereby changing slightly its height above the floor level.

The 90 percent confidence limits for the slopes (b) and the intercepts (a) of the linear regression lines are listed in Table 3 for the test variables. The table lists also the standard estimates of error (s_e) for the measured variables and the corresponding degrees of freedom (df=N-2). It is assumed that the measured values for a given computed value form a normal distribution (1, p. 197-198). The confidence limits for the slope and intercept are computed using the standard error of the mean and the critical t-value (.05 level significance) for the degrees of freedom (1, Table A5, p. 464). The confidence bounds for the standard errors of estimate are computed using the critical values (.05 and .95 level of significance) of the ratio of Chi-squared to degrees of freedom (1, Table A6b, p. 466).

The slope of the linear regression line should be equal to unity (b=1) and the intercept equal to zero (a=0) when the matched samples are equal within the limits of the measurement error. Furthermore, the standard error of measurement should be equal to the measurement error for the equipment and procedure. These values are contained within the confidence limits for the transmittance as shown in Table 3.

TABLE 1

Student's t-Test for Matched Samples

Variable	$\overline{D}$	s_D	t_D	df	t_c*
transmittance	.0112	.0471	.8257	11	2.228
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*.05 level of significance for a two-tailed test.

A comparison of the t-values listed in Table 1 for the scores, with the critical t-values, shows that there is not sufficient reason to reject the hypothesis that the measured and computed transmittance values are the same. However, the hypothesis that the measured and computed coordinate values are not different must be rejected at least at the .05 level of significance (see Discussion).

The matched data for the transmittance and the three coordinates were treated in linear regression analyses (6, p. 152-170). Table 2 lists the Pearson's correlation coefficients (r) for the matched data, the degrees of freedom (df) given by df=N-2 where N is the number of matched data, and the corresponding critical r-value (r_c) at the .01 level of significance for a two tailed test (6, Table D, p. 258). The table also lists the slope (b) and intercept (a) of the linear regression lines and the corresponding standard errors of estimate (s_e). The coefficients of the linear regression line were computed using the method of least squares.

The correlation coefficients listed in Table 2 are nearly equal to unity. A comparison of the coefficients with the critical values shows that the coefficients are statistically significant from zero at the .01 level. The matched data are linearly related in the statistical sense.

DISCUSSION

It was shown in the results that the mean difference scores listed in Table 1 for the x-, y-, and z-coordinates are statistically significant from zero. The mean difference scores are equal to the differences between the sample means for the measured and computed coordinates. The mean differences may be the errors for centering and aligning the coordinate

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*.01 level of significance for a two-tailed test.

system of the test-area floor with that of the mockup. The centering was done by plumb bob and the alignment by tape measure and line of sight. The height of the mockup's top canopy surface above the test area floor was measured by tape sometime after the test. The intervening period was used by other personnel to measure the coordinates of the vertices of the mockup frame. The mockup was inadvertently braced during the operation thereby changing slightly its height above the floor level.

The 90 percent confidence limits for the slopes (b) and the intercepts (a) of the linear regression lines are listed in Table 3 for the test variables. The table lists also the standard estimates of error (s_e) for the measured variables and the corresponding degrees of freedom (df=N-2). It is assumed that the measured values for a given computed value form a normal distribution (1, p. 197-198). The confidence limits for the slope and intercept are computed using the standard error of the mean and the critical t-value (.05 level significance) for the degrees of freedom (1, Table A5, p. 464). The confidence bounds for the standard errors of estimate are computed using the critical values (.05 and .95 level of significance) of the ratio of Chi-squared to degrees of freedom (1, Table A6b, p. 466).

The slope of the linear regression line should be equal to unity (b=1) and the intercept equal to zero (a=0) when the matched samples are equal within the limits of the measurement error. Furthermore, the standard error of measurement should be equal to the measurement error for the equipment and procedure. These values are contained within the confidence limits for the transmittance as shown in Table 3.

TABLE 3

Confidence Limits (90%) for the Slope (b) and the Intercept (a) of the Linear Regression Line, and the Standard Errors of Estimate (s_e)

Variable	df	Slope (b)		Intercept (a)		Error (s_e)	
		max	min	max	min	max	min
transmittance	10	1.0119	.8834	.0322	-.0143	.1252	.0328
x-coordinate	18	.9403	.8887	.7139	-.0017	1.8567	.7695
y-coordinate	18	1.0272	.9702	1.3736	.3034	2.7767	1.091
z-coordinate	18	1.1603	1.0359	-10.2098	-11.1008	2.3119	.9084

The confidence limits in Table 3 for the coordinates do not in all cases contain the expected values noted above for the regression line slopes and intercepts. The confidence limits for the slopes of the x and z coordinates are close to, but do not contain the expected value (b=1). Similarly, the limits for the y coordinate's intercept are close to the expected value (a=0) but do not contain it. This discrepancy is highly noticeable in the case of the z coordinate's intercept which is on the order of -10 inches. However, the values of the z coordinate range from 80 to 100 inches. The line intercept must correct for an additional increment in value due to the slope (or the order of 0.1x90=9 inches), as well as the 1.62 inches mean difference between the computed and measured samples. A slight tilt of the mockup on the bay area floor, not accounted for in the alignment measurements, is a reasonable explanation for the slope values of the x and z coordinate samples. The observer would dismount from the mockup during the second test phase to assist in coordinate measurements. The resulting weight shift in the mockup between the times of observing and measurement could be the cause of a tilt in the mockup frame.

Similarly, the lower limits on the standard errors of estimate are larger (on the order of 1 inch) than would be expected for the equipment and procedure used to measure the positions of the light image (see Apparatus). However, an in-depth error analysis would include the effects of errors in locating the light source on the bay area floor and in pinpointing the position of the image of the 1½-inch diameter light bulb. These additional factors may explain the otherwise larger-than-expected standard errors of estimate.

RECOMMENDATIONS FOR FURTHER RESEARCH

The following is recommended:

1. The model should be tested using cylindrically shaped panels as well as the planar panels used in this test. The use of the surveyor's level to measure coordinate values should be extended to measuring the positions of the light source and the surface image points as well as the mockup frame vertices.

2. The locations on the canopy surface of the primary reflections of the instrument panel lights can be computed using the computer model. This area of application should be investigated further.

CONCLUSION

The US Army Human Engineering Laboratory (USAHEL) has experimentally verified a computer model for the internal light reflections on the transparent surfaces of helicopter canopies. The model was verified using a mockup of the Model 209 AH-1S Helicopter with the flat plate canopy design. The transmittance values and the coordinates of the light images on the canopy surfaces were measured for a wide range of light source positions. A matched sample was then computed for the source positions using the computer model.

The matched values of the measured and computed samples show a high correlation. The Pearson's correlation coefficients for a linear regression analyses are greater than 0.98 and the coefficients are significantly different from zero at the .01 level. However, the mean differences between the measured and computed coordinate samples are on the order of 0.6 inches to 1.62 inches. Furthermore, the slopes and intercepts of the linear regression lines are not the expected values for all of the coordinate samples. These differences are presumably due to the inaccuracies in the alignment of the mockup with the coordinate system on the test-area floor.

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APPENDIX A

TEST DATA AND STATISTICAL ANALYSES

TEST DATA AND STATISTICAL ANAYSES

The measured and computed values of the light image transmittance and coordinates are listed in Table 1A for the test positions of the light source. The table lists the transmittance and coordinates of the matched direct view and primary reflection data for the first phase. The second phase data includes the coordinates of the matched direct view and primary reflection data, as well as the unmatched reflection data.

The light image coordinates are in the coordinate system (x_m, y_m, z_m) of the mockup, which was aligned as closely as possible to the design specifications for the actual aircraft. The coordinates of the light source positions are in the coordinate system (x_f, y_f, z_f) laid out on the test area floor. The origin of the mockup's system was located in the floor system as follows: $x_f = o$, $y_f = 24.75$, and $z_f = -30.586$ inches. The z axis of the mockup was directed parallel to that of the floor system, while the y axis was directed in the parallel but opposite direction of that of the floor. A light source located at the coordinates x_f, y_f, z_f in the floor system was located at the mockup coordinates: $x_m = -x_f$, $y_m = -y_f + 24.75$ and $z_m = z_f + 30.586$ inches.

The attached computer program MSTT was used to compare the matched data in a student's t-test. The data were treated in a linear regression analysis using the program LSA attached below.

TABLE 1A

Transmittance (T) and Position Coordinates (x,y,z) of the Direct View (D) and Primary (P) Reflected Images for the Light Source Test Positions

Light Source				Computed				Measured			
x	y	z	Type	x_c	y_c	z_c	T_c	x_m	y_m	z_m	T_m
I. First Test Phase Data											
60.	-52.	12.	P	-7.65	130.14	105.97	.0734				.0901
36.	-40.4	12.	P	-5.96	128.49	105.97	.0543				.0502
36.	7.56	36.	D	-14.77	87.06	83.12	.7235				.7907
60.	43.57	24.	D	-15.29	96.83	84.5	.7672				.7326
			P	15.34	111.74	91.86	.1019				.0858
48.	-88.4	48.	D	-16.75	129.62	89.31	.8693				.9002
			P	15.14	133.53	95.36	.0658				.1089
72.	-64.4	48.	D	-16.38	128.17	91.76	.8672				.7698
			P	15.01	131.83	96.2	.0663				.0494
72.	-4.43	48.	D	-16.45	115.07	91.74	.8239				.7531
			P	14.88	121.62	96.28	.076				.0673
12.	31.56	24.	P	-2.84	114.26	105.98	.1347				.0908
II. Second Test Phase Data											
48.	-100.44	36.	D	-17.45	133.78	84.5		-16.	133.69	83.17	
			P	-9.31	136.09	105.96	Note (1)				
60.	-88.44	36.	D	-17.11	131.31	86.85		-15.75	131.31	85.16	
			P					13.78	136.91	91.81	Note (2)
36.	-76.44	12.	P	-4.24	133.61	105.96		-2.72	133.22	105.97	

(Continued)

TABLE 1A (Continued)

Transmittance (T) and Position Coordinates (x,y,z) of the Direct View (D) and Primary (P) Reflected Images for the Light Source Test Positions

Light Source			Type	Computed				Measured			
x	y	z		x_c	y_c	z_c	T_c	x_m	y_m	z_m	T_m
72.	-40.44	48.	D	-16.48	121.30	91.38		-15.25	121.94	88.91	
			P	14.97	128.50	96.20		14.28	130.66	93.31	
84.	-40.44	24	D	-17.18	123.19	86.67		-15.75	123.69	84.66	
			P	15.31	129.80	93.67		14.66	132.16	91.31	
48.	-28.44	24.	D	-18.40	104.99	79.24		-16.12	107.94	78.16	
			P	-7.29	124.43	105.97		-5.72	123.97	105.97	
36.	-4.43	36.	D	-15.11	91.15	82.85		-15.5	90.69	80.41	
			P	-6.75	115.9	105.98		-5.22	115.47	105.97	
			P	15.34	115.75	92.24		14.782	117.16	89.44	
72.	7.57	48.	D	-16.54	109.71	91.36		-15.5	111.94	88.91	
			P	14.89	121.78	96.18		14.532	123.16	93.31	
12.	19.57	12.	P					-5.34	73.22	92.81	Note (3)
36.	31.57	48.	D	-13.53	81.72	88.8		-12.78	81.97	87.69	
			P	14.01	95.89	94.2		14.782	99.66	92.31	
60.	31.57	24.	P	15.35	116.45	92.24		14.782	117.16	90.31	
12.	43.57	48.	D	-4.86	67.87	87.83		-3.375	68.94	88.75	
24.	43.57	36.	P	13.61	82.38	88.62		13.78	83.41	87.81	
60.	43.57	48.	D	-14.46	98.97	91.14		-15.	96.44	88.41	
			P	14.86	113.75	95.79	Note(4)				

NOTES - An examination of the mockup showed the following reasons for the occurrence of unmatched data:

(1) The computed reflected image was actually blocked from the observer's view by the brow pad which was not included in the mockup frame vertice data.

(2) The observed image of the 1½-inch diameter bulb appeared at the window edge and was not computed for the point source used in the model.

(3) The mockup nose was assumed to be 2 inches longer in the model than it actually was, and the light source was placed just under the nose.

(4) The computed image was actually blocked from view by two overlapping frame edges, but they were represented as slightly separated in the model.

(Concluded)

```
SMYTH,STMFZ.
ACCOUNT,HE***.
FTN.
LGO.
      PROGRAM MSTT(INPUT,OUTPUT,TAPE2=INPUT,TAPE1=OUTPUT)
C T-TEST FOR MATCHED SAMPLES
C XM, RANDOM VARIABLE MEASURED BY TESTING
C XC, COMPUTED VALUES FOR TEST MEASUREMENT CONDITIONS
C N, NUMBER OF PAIRED OBSERVATIONS
      DIMENSION XM(100),XC(100),FL(100),D(100)
      READ(2,1000)NR
      DO 100 IR=1,NR
C READ IN TEST AND COMPUTED VARIBLE VALUES
      READ(2,999)(FL(I),I=1,40)
  999 FORMAT(40A2)
      WRITE(1,999)(FL(I),I=1,40)
      READ(2,1000)N
 1000 FORMAT(2X,I4)
      XN=N
      READ(2,1001)(XM(I),I=1,N)
 1001 FORMAT(2X,6(F10.4,2X))
      READ(2,1001)(XC(I),I=1,N)
      WRITE(1,1011)N
 1011 FORMAT(2X,'TEST DATA'/2X,'NO. MEASUREMENTS=',I4/2X,'TEST MEASUREME
     QNTS')
      WRITE(1,1012)(XM(I),I=1,N)
 1012 FORMAT(6(2X,F10.4))
      WRITE(1,1013)(XC(I),I=1,N)
 1013 FORMAT(2X,'COMPUTED VALUES'/6(2X,F10.4))
      DO 5 I=1,N
      D(I)=XC(I)-XM(I)
    5 CONTINUE
      WRITE(1,1015)(D(I),I=1,N)
 1015 FORMAT(2X,"DIFFERENCES"/6(2X,F10.4))
      SD=0.
      SD2=0.
      DO 10 I=1,N
      SD=SD+D(I)
      SD2=SD2+D(I)*D(I)
   10 CONTINUE
      SMD=SD/XN
      STD=SQRT((SD2-SD*SD/XN)/(XN-1.))
      TV=SD/SQRT((XN*SD2-SD*SD)/(XN-1.))
      WRITE(1,1014)SMD,STD,TV
 1014 FORMAT(2X,"MEAN-DIFFERENCE",2X,F10.4,2X,"STANDARD DEVIATION",
     Q2X,F10.4/2X,"T-TEST VALUE",2X,F10.4)
  100 CONTINUE
      STOP
      END
```

4					
TRANSMITTANCE					
12					
.7907	.7326	.9002	.7698	.7531	.0901
.0502	.0856	.1069	.0494	.0673	.0906
.7235	.7672	.8693	.8672	.8239	.0734
.0543	.1019	.0659	.0663	.076	.1347
X-POSITION					
20					
-16.	-15.75	-15.25	-15.75	-16.12	-15.5
-15.5	-12.76	-3.375	-15.	-2.72	14.28
14.66	-5.72	-5.22	14.78	14.53	14.78
14.78	13.78				
-17.45	-17.11	-16.48	-17.18	-18.4	-15.11
-16.47	-13.53	-4.86	-14.46	-4.24	14.97
15.31	-7.29	-6.75	15.34	14.89	14.01
15.35	13.61				
Y-POSITION					
20					
133.69	131.31	121.94	123.69	107.94	90.69
111.94	81.97	68.94	96.44	133.72	130.66
132.16	123.97	115.47	117.16	123.16	99.66
117.16	83.41				
133.78	131.31	121.3	123.19	104.99	91.15
112.43	81.72	67.87	98.97	133.61	128.5
129.8	124.43	115.9	115.75	121.78	95.89
116.45	82.38				
Z-POSITION					
20					
83.17	85.16	88.91	84.66	78.1	60.41
88.91	87.69	88.75	88.41	105.97	93.31
91.31	105.97	105.97	89.44	93.31	92.31
90.31	87.81				
84.5	86.85	91.38	86.67	79.24	62.85
91.74	88.8	87.83	91.14	105.96	96.2
93.67	105.97	105.98	92.24	96.18	94.2
92.24	86.62				

```
SMYTH,STMFZ.
ACCOUNT,HE***.
FTN.
LGO.
      PROGRAM LSA(INPUT,OUTPUT,TAPE2=INPUT,TAPE1=OUTPUT)
C LINEAR REGRESSION ANALYSIS BY LEAST SQUARES
C XM, RANDOM VARIABLE MEASURED BY TESTING
C XC, COMPUTED VALUES FOR TEST MEASUREMENT CONDITIONS
C N, NUMBER OF PAIRED OBSERVATIONS
      DIMENSION XM(100),XC(100),FL(100)
      READ(2,1000)NR
      DO 100 IR=1,NR
C READ IN TEST AND COMPUTED VARIBLE VALUES
      READ(2,999)(FL(I),I=1,40)
  999 FORMAT(40A2)
      WRITE(1,999)(FL(I),I=1,40)
      READ(2,1000)N
 1000 FORMAT(2X,I4)
      XN=N
      READ(2,1001)(XM(I),I=1,N)
 1001 FORMAT(2X,6(F10.4,2X))
      READ(2,1001)(XC(I),I=1,N)
      WRITE(1,1011)N
 1011 FORMAT(2X,'TEST DATA'/2X,'NO. MEASUREMENTS=',I4/2X,'TEST MEASUREME
     ONTS')
      WRITE(1,1012)(XM(I),I=1,N)
 1012 FORMAT(6(2X,F10.4))
      WRITE(1,1013)(XC(I),I=1,N)
 1013 FORMAT(2X,'COMPUTED VALUES'/6(2X,F10.4))
C READ FOR CONFIDENT INTERVAL CALCULATIONS THE TYPE 1 ERROR VALUE AND
C CORRESPONDING TWO-SIDED STUDENT'S T-VALUE AT N-2 DEGREES OF FREEDOM")
      READ(2,1010)AT,TV
 1010 FORMAT(2X,3(F10.4,2X))
C READ FOR TEST VARIANCE CALCULATIONS TYPE 1 ERROR LEVEL AND CORRESPONDI
C RATIO OF CHI-SQUARED TO DEGREES OF FREEDOM
      READ(2,1010)AC,CFU,CFL
C COMPUTE LINEAR CORRELATION COEFFICIENT FOR RAW MEASURED AND COMPUTED V
      SMC=0.
      SM=0.
      SC=0.
      SC2=0.
      SM2=0.
      DO 10 I=1,N
      SM=SM+XM(I)
      SC=SC+XC(I)
      SMC=SMC+XM(I)*XC(I)
      SM2=SM2+XM(I)*XM(I)
      SC2=SC2+XC(I)*XC(I)
   10 CONTINUE
      SSC=SQRT((SC2-SC*SC/XN)/(XN-1.))
      RXY2=(XN*SMC-SC*SM)**2
      RXY2=RXY2/((XN*SC2-SC*SC)*(XN*SM2-SM*SM))
      RXY=SQRT(RXY2)
      WRITE(1,1002)RXY,RXY2
 1002 FORMAT(2X,'CORRELATION COEFFICIENT=',F7.4,2X,'SQUARED COEFFICIENT=
     0',F10.4)
C COMPUTE LINEAR REGRESSION EQUATION COEFFICIENTS FOR ESTIMATING MEASURE
C XM(ESTIMATED)= B*XC+A
      AVM=SM/XN
      AVC=SC/XN
```

```
      B=RXY*(XN*SM2-SM*SM)/(XN*SC2-SC*SC)
      A=AVM-B*AVC
      WRITE(1,1003)B,A
 1003 FORMAT(2X,'REGRESSION EQUATION COEFFICIENTS, B=',F10.4,2X,'A=',F10
     0.4)
C COMPUTE STANDARD ERROR OF ESTIMATE
      SE=0.
      DO 20 I=1,N
      SE=SE+(XM(I)-B*XC(I)-A)**2
   20 CONTINUE
      SE=SQRT(SE/XN)
      WRITE(1,1004)SE
 1004 FORMAT(2X,'STANDARD ERROR OF ESTIMATE=',F10.4)
C COMPUTE CONFIDENT INTERVAL FOR REGRESSION EQUATION COEFFICIENTS
      RGA=TV*SE/SQRT(XN)
      RGB=TV*SE/(SQRT(XN-1.)*SSC)
      BL=B-RGB
      BU=B+RGB
      AL=A-RGA
      AU=A+RGA
      WRITE(1,1005)AI
 1005 FORMAT(2X,'CONFIDENT INTERVAL TYPE 1 ERROR LEVEL, A=',F10.4)
      WRITE(1,1006)BL,BU
 1006 FORMAT(2X,'REGRESSION EQUATION COEFFICIENT'/2X,'LOWER LIMIT, BL=',
     0F10.4,' UPPER LIMIT, BU=',F10.4)
      WRITE(1,1007)AL,AU
 1007 FORMAT(2X,'LOWER LIMIT, AL=',F10.4,' UPPER LIMIT, AU=',F10.4)
C COMPUTE ACCEPTIBLE TEST-VARIANCE DUE TO TEST PROCEEDURE AND INSTRUMENT
      STU=SE/SQRT(CFU)
      STL=SE/SQRT(CFL)
      WRITE(1,1009)AC,STU,STL
 1009 FORMAT(2X"TEST VARIANCE TYPE 1 ERROR LEVEL, A=",F10.4,2X/
     02X,"TEST-VARIANCE UPPER LIMIT, STU=",F10.4/2X,
     0"LOWER LIMIT, STL=",F10.4)
  100 CONTINUE
      STOP
      END
     4
 TRANSMITTANCE
    12
  .7907      .7326      .9002      .7698      .7531      .0901
  .0502      .0858      .1089      .0494      .0673      .0908
  .7235      .7672      .8693      .8672      .8239      .0734
  .0543      .1019      .0658      .0663      .076       .1347
  .1         1.812
  .1         .126       1.83
 X-POSITION
    20
  -16.       -15.75     -15.25     -15.75     -16.12     -15.5
  -15.5      -12.78     -3.375     -15.       -2.72      14.26
  14.66      -5.72      -5.22      14.76      14.53      14.76
  14.78      13.78
  -17.45     -17.11     -16.48     -17.18     -18.4      -15.11
  -16.47     -13.53     -4.86      -14.46     -4.24      14.97
  15.31      -7.29      -6.75      15.34      14.89      14.01
  15.35      13.61
  .1         1.734
  .1         .247       1.6
```

```
Y-POSITION
   20
 133.69        131.31        121.94        123.69        107.94        90.69
 111.94        81.97         68.94         96.44         133.72        130.66
 132.16        123.97        115.47        117.16        123.16        99.66
 117.16        83.41
 133.78        131.31        121.3         123.19        104.99        91.15
 112.43        81.72         67.87         98.97         133.61        128.5
 129.8         124.43        115.9         115.75        121.78        95.69
 116.45        82.38
 .1            1.734
 .1            .247          1.6
Z-POSITION
   20
 83.17         85.16         88.91         84.66         76.1          80.41
 88.91         87.69         88.75         88.41         105.97        93.31
 91.31         105.97        105.97        89.44         93.31         92.31
 90.31         87.81
 84.5          86.85         91.38         86.67         79.24         82.85
 91.74         88.8          87.63         91.14         105.96        96.2
 93.67         105.97        105.98        92.24         96.18         94.2
 92.24         88.62
 .1            1.734
 .1            .247          1.6
```

APPENDIX B

PRIMARY ORDER REFLECTIONS

PRIMARY ORDER REFLECTIONS

The computation of the transmittance and position coordinates of the direct view and primary order reflection images are discussed in this section. The computations for a direct view image are discussed first. A primary order reflection occurs when the light ray from the light source is reflected once before reading the observer's eye. We consider next the computations for the primary order reflections from a planar surface, then that from a cylindrical surface.

DIRECT VIEW IMAGES

The computational procedures for direct view image points are derived from established techniques. The position coordinates are first computed for the point where the straight line ray from the light source to the pilot's eye position intercepts a window surface. The directional cosines are computed for the ray from the end position coordinates and the length. The interception point is computed from the light source position, the directional cosines of the ray and the parameters of the surface using established techniques for a planar surface (Smyth, June, 1977, App A) and a cylindrical surface (Smyth, July 1977, App A). The interception point is tested against the window edges to ensure enclosure. The light transmittance is computed next from the angle of incidence between the ray and the surface normal (Smyth, June 1977, App A).

PRIMARY ORDER REFLECTIONS FROM A PLANAR SURFACE

The coordinates of the reflection point on the window surface are a function of the light source position, the pilot's eye position, the surface normal and the position of a window vertex. We consider the geometry (see Figure 1B) formed by the positions of the pilot's eye (P_o = x_o, y_o, z_o), the light source (P_s = x_s, y_s, z_s) and the reflection point (P_r = x_r, y_r, z_r). The plane containing these three points contains also the surface normal (a_n, b_n, c_n) by the laws of reflection. Furthermore, the angle between the ray $P_s P_r$ and the surface normal is equal and opposite to that between the ray $P_o P_r$ and the surface normal by the same law.

The straight line, $P_s P_o$, from the light source to the pilot's position is specified by its starting position (P_s : x_s, y_s, z_s), the directional cosines (a_{os}, b_{os}, c_{os}) and its length (R_{os}). The last two parameter sets are easily computed from the known end positions. We denote the point where the line $P_s P_o$ intersects the extension of the surface normal by $P_1(x_1, y_1, z_1)$. The extension separates the triangle $P_s P_r P_o$ into two smaller triangles with sides a and b such that $a + b = R_{os}$. We find it useful to derive the coordinates of the point (P_1) as an intermediate step in the derivation.

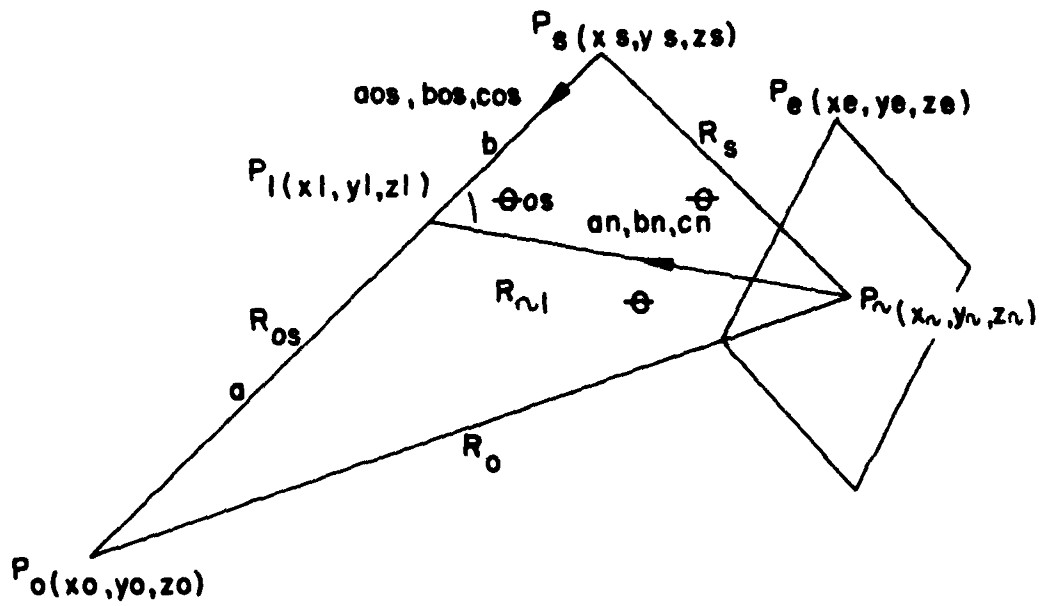

Figure 1B. Primary reflection from planar surface.

The coordinates of the point, P_1, are determined from the ratio of the length of the line $P_s P_r$ to that of the line $P_s P_r$; i.e., $Q = R_s/R_r$. The ratio is computed using:

1. the cosine of the angle between the line $P_r P_e$ and the surface normal.

2. that of the line $P_r P_s$ and the surface normal, and

3. that of the line $P_r P_o$ and the normal.

The first term is equal to zero while the second and third are equal to each other. The results are:

$$Q = \frac{a_n(x_e - x_s) + b_n(y_e - y_s) + c_n(z_e - z_s)}{a_n(x_e - x_o) + b_n(y_e - y_o) + c_n(z_e - z_o)} \qquad (1)$$

The length (a) of the line $P_s P_e$ is determined by the law of sines for the two triangles and the expression $R_{os} = a + b$,

$$a = \frac{QR_{os}}{1+Q} \qquad (2)$$

The coordinates of the point, P_1, are given by:

$$\begin{aligned} x_1 &= x_s + a \cdot a_{os}, \\ y_1 &= y_s + a \cdot b_{os}, \\ z_1 &= z_s + a \cdot c_{os}. \end{aligned} \qquad (3)$$

The coordinates of the primary reflection point P_r are determined by the point P_1, the directional cosines of the surface normal, and the distance, R_{1r}, from the point, P_1, to the surface in the direction of the surface normal. This distance may be computed by established techniques (Smyth, June 1977, App A).

$$R_{1r} = a_n(x_1 - x_e) + b_n(y_1 - y_e) + c_n(z_1 - z_e). \qquad (4)$$

The coordinates of the reflection point (P_r) are,

$$\begin{aligned} x_r &= x_1 - a_n R_{1r}, \\ y_r &= y_1 - b_n R_{1r}, \\ z_r &= z_1 - c_n R_{1r}, \end{aligned} \qquad (5)$$

The point, P_r, is a reflection point for the light source if the value of Q is given by equation (1) is greater or equal to zero; i.e., $Q \geq o$, for then the light source and observer are on the same side of the panel surface.

The reflection point (P_r) is tested against the window edges to ensure enclosure. The light reflectance is computed from the angle of incidence between the ray and the surface normal (Smyth, June 1977, App A).

PRIMARY ORDER REFLECTIONS FROM A CYLINDRICAL SURFACE

The computation of the primary reflection points for a cylindrical surface will be derived first for a simple case and then extended to all cases in general. We consider a cylindrical surface with the following parameters (see Figure 2B): (1) the origin for the cylindrical axis is located at the origin of the coordinate system, (2) the cylindrical axis is directed along the y axis of the coordinate system, and (3) the cylindrical radius is equal to unity. The analysis is similar to that developed above for the planar surface.

Consider the geometry formed by the positions of the light source, the reflection point and the pilot's eye. The straight line from the light source to the eye is specified by its starting position, the directional cosines (a_{os},b_{os},c_{os}) and the line length (R_{os}). The surface normal(a_n,b_n, c_n) is contained within the plane defined by the three points P_s,P_r and P_o. We let the point where the extension of the surface normal intersects the line P_sP_o be denoted by P_1 and its coordinates by x_1, y_1, and z_1. The line separates the triangle $P_sP_rP_o$ into two smaller triangles and the P_sP_o into two line segments of lengths a and b. The length (a) of the line P_sP_1 is determined by the law of sines for the two triangles and the expression R_{os} = a+b. The length (a) is given by the equation (2), where Q is the ratio of the length of the line P_sP_r to that of the line $P_r P_o$; i.e., $Q = R_s/R_o$. The coordinates of the point P_1 are given by equations (3).

The surface normal is orthogonal to the cylindrical axis, and the distance (R) along the surface normal from the point, P_1, to the point (o,y_1,o) on the cylindrical axis is given by,

$$R = ((x_s + Qx_o)^2 + (z_s + Qz_o)^2)^{1/2} /(1 + Q). \tag{6}$$

The directional cosines of the surface normal at the reflection point may now be computed as,

$$\begin{aligned} a_n &= (x_s + Qx_o)/R, \\ b_n &= 0, \\ c_n &= (z_s + Qz_o)/R. \end{aligned} \tag{7}$$

Finally, since the cylinder radius is unity, the coordinates of the reflection point (P_r) are:

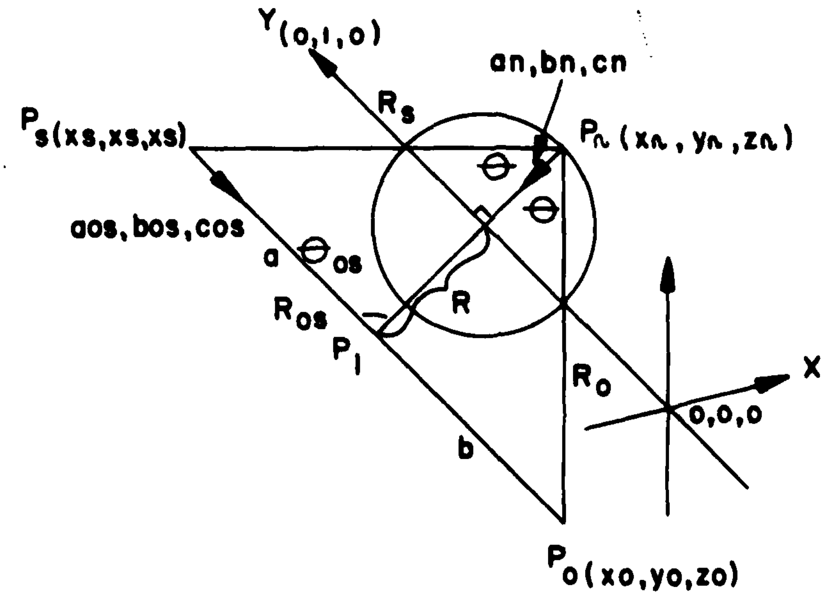

Figure 2B. Primary reflection from a cylindrical surface.

$$x_r = -a_n,$$

$$y_r = y_s + a \cdot b_{os}, \tag{8}$$

$$z_r = -c_n.$$

The Q factor used in equations (2) and (3) is determined by setting the cosine of the angle between the line P_rP_s and the surface normal, equal to that of the angle between the line P_rP_o and the normal. The result is a fourth order polynominal,

$$\alpha_4Q^4 + \alpha_3Q^3 + \alpha_2Q^2 + \alpha_1Q + \alpha_o = o, \tag{9}$$

where $\alpha_o = (x_s^2 + z_s^2) - x_s^2 - z_s^2,$

$\alpha_1 = -2\ (x_ox_s + z_oz_s - x_s^2 - z_s^2),$

$\alpha_2 = -(x_o^2 + x_s^2 + z_o^2 + z_s^2 - 4x_ox_s - 4z_oz_s + 2\ (x_o^2 + z_o^2)\ (x_s^2 + z_s^2)),$

$\alpha_3 = -2\ (x_ox_s + z_oz_s - x_o^2 - z_o^2),$

$\alpha_4 = (x_o^2 + z_o^2) - x_o^2 - z_o^2.$

The equation may be solved by synthetic division and the Newton-gradient method or other numerical solution techniques. (Hildebrand, p. 451).

There are, in general, four solutions to equation (9), each corresponding to a point on the cylindrical surface. The point is a reflected image of the light source if the light source and pilot's position are on the same side of the surface. This is the case if the ratio of the cosines of the angles between the rays P_sP_r and P_oP_r and the surface normal,

$$Q_{so} = \frac{1 - a_nx_s - c_nz_s}{1 - a_nx_o - c_nz_o} \tag{10}$$

is larger than or equal to zero; i.e., $Q_{so} \geq o$.

The computary scheme worked out above for the simple cylinder case is used as a solution space. The coordinates of the positions of the light source and pilot are transformed into their equivalent values in the solution space. The reflection points are computed and the coordinates are transformed back into the original problem space. The coordinate transformation from the problem space to the solution space consists of four steps: (Newman, Ch. 3)

1. Translate the origin (x_c, y_c, z_c) of the cylindrical axis into the origin of the coordinate system of the solution space, (2) rotate the cylindrical axis (a_c, b_c, c_c) clockwise about the x axis until it is

aligned with the y axis of the solution space, (3) rotate the cylindrical axis clockwise about the z axis until the z axes are aligned, and (4) scale the original space by the cylinder radius, R_c.

The translation of the coordinates (x,y,z) into their equivalent value (x^1,y^1,z^1) in the solution space is performed by matrix multiplication; i.e.,

$(x^1,y^1,z^1,1) = (x,y,z,1)\ M_T M_x M_z M_s$. The corresponding matrixes are given by:

$$M_T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -x_c & -y_c & -z_c & 1 \end{pmatrix},$$

$$M_x = \frac{1}{v_c}\begin{pmatrix} v_c & 0 & 0 & 0 \\ 0 & b_c & c_c & 0 \\ 0 & -c_c & b_c & 0 \\ 0 & 0 & 0 & v_c \end{pmatrix},$$

$$M_z = \begin{pmatrix} v_c & -a_c & 0 & 0 \\ a_c & v_c & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \tag{11}$$

$$M_s = \frac{1}{r_c}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & r_c \end{pmatrix},$$

where $v_c = \sqrt{b_c^2 + c_c^2}$.

Once the reflection points are solved, the position coordinates (x_r^1, y_r^1, z_r^1) are transformed back into their equivalent values (x_r, y_r, z_r) in the problem space. This operation is done by an inverse matrix transformation; i.e., $(x_r, y_r, z_r, 1) = (x_r^1, y_r^1, z_r^1, 1)\ M_s^{-1} \cdot M_z^{-1} \cdot M_z^{-1} \cdot M_r^{-1} \cdot M_T^{-1}$. The corresponding matrixes are given by:

$$M_T^{-1} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ x_c & y_c & z_c & 1 \end{pmatrix},$$

$$M_x^{-1} = \frac{1}{v_c} \begin{pmatrix} v_c & 0 & 0 & 0 \\ 0 & b_c & c_c & 0 \\ 0 & -c_c & b_c & 0 \\ 0 & 0 & 0 & v_c \end{pmatrix},$$

$$M_z^{-1} = \begin{pmatrix} a_c & v_c & 0 & 0 \\ -v_c & a_c & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}, \tag{12}$$

$$M_s^{-1} = r_c \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1/r_c \end{pmatrix}.$$

The reflection points are checked against the window edges to ensure enclosure (Smyth, July 1977, App A). The light reflectance is computed from the angle of incidence between the ray and the surface normal (Smyth, June 1977, App A).

APPENDIX C

COMPUTER PROGRAM

Computer Program

The computer program used to compute the transmittance and coordinate values of the matching sample is attached below. The listing includes the program and subroutines, the mockup frame vertices input data, the position and orientation of the mockup on the test-area floor, and the positions of the light source used in the test. The program is written in the Fortran IV language and was run on the CDC 7500 Computer System. The subroutines are listed as follows:

1. CONTL- Main program calls for read in of data and computations.

2. READV- Subroutine reads in frame vertice coordinate data. Called by CONTL.

3. NORML- Subroutine computes surface normal for each canopy window. Called by CONTL.

4. FLEG- Subroutine reads in mockup position and orientation on test-area floor. Called by CONTL.

5. SLIGP- Subroutine reads in test light position on test-area floor and calls for computation of light images for the left and right eye of the observer. Called by CONTL.

6. STPS- Subroutine converts the light source position into the coordinate system of the mockup, and calls for the computation of the direct view and primary reflected images. Called by SLIGP.

7. PRNT- Subroutine prints out direct view and reflected image point information. Called by SLIGP.

8. MTRNL-
   MROTX-
   MROTY-
   MROTZ-
   MSCAL- Subroutines called by STPS to convert light source position on test-area floor into coordinate system of mockup.

9. COMPO- Subroutine controls computation of direct view image position coordinates and transmittance. Called by STPS.

10. COMPL- Subroutine controls computation of primary reflection image position coordinates and transmittance. Called by STPS.

11. INTEC- Subroutine computes direct view image point on a planar surface for a given light source position and checks whether point is enclosed by surface edges. Called by COMPO and COMPL.

12. INTCY- Subroutine computes direct view image point on cylindrical surface and determines whether point is enclosed by edges of cylindrical window. Called by COMPO and COMPL.

13. TRSCY- Subroutine converts coordinates of a cylindrical coordinate system into a rectangular system. Called by INTCY and INTS when testing a surface point against surface edges.

14. INTPL- Subroutine computes primary reflection point coordinates for a planar surface and determines whether the point is within the surface edges. Called by COMPO and COMPL.

15. INTCL- Subroutine computes primary reflection point coordinates for a cylindrical surface and determines whether the point is within the surface edges. Called by COMPO and COMPL.

16. TRANC- Subroutine converts point into cylindrical solution space. Called by INTCL.

17. SPOLY- Subroutine computes coordinates of image points in cylindrical solution space. Called by INTCL.

18. SOLN- Subroutine checks image point to ensure that it is reflected and controls conversion to problem space. Called by INTCL.

19. INUC- Subroutine converts image point from cylindrical solution space into problem space. Called by SOLN.

20. INTS- Subroutine determines whether reflected image point on cylindrical surface is enclosed within surface edge. Called by INTCL.

21. COMP- Subroutine computes transmittance and reflectance for image point. Called by COMPO and COMPL.

```
SMYTH,STMFZ.
ACCOUNT,HE***.
FTN(SL,R).
MAP,ON.
LGO.
      PROGRAM CONTL(INPUT,OUTPUT,TAPE2=INPUT,TAPE3=OUTPUT)
      CALL READV
      CALL NORML
      CALL FLEG
      CALL SLIGP
      STOP
      END
      SUBROUTINE READV
C READ IN SURFACE VERTICES
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      READ(2,1000)
 1000 FORMAT()
      READ(2,1000)
      READ(2,1001)NT,NB,NC,NP,NA,ND
 1001 FORMAT(6(2X,I3))
      READ(2,1000)
      READ(2,1002)(NV(I),I=1,ND)
 1002 FORMAT(8(2X,I3))
      READ(2,1000)
      DO 10 J=1,8
      READ(2,1002)(NVR(I,J),I=1,ND)
   10 CONTINUE
      READ(2,1000)
      READ(2,1003)(XV(I),I=1,NT)
 1003 FORMAT(8(2X,F7.3))
      READ(2,1000)
      READ(2,1003)(YV(I),I=1,NT)
      READ(2,1000)
      READ(2,1003)(ZV(I),I=1,NT)
      READ(2,1000)
      READ(2,1002)NCY
      IF(NCY.EQ.0)GOTO 25
      READ(2,1002)(NSC(I),I=1,NCY)
      DO 20 I=1,NCY
      KP=NSC(I)
   20 READ(2,1002)(NSP(I,K),K=1,KP)
      READ(2,1004)(XC(I),YC(I),ZC(I),AE(I),BE(I),CE(I),RC(I),I=1,NCY)
 1004 FORMAT(7(2X,F7.3))
   25 CONTINUE
      READ(2,1000)
      READ(2,1003)XO,YO,ZO
      RETURN
      END
      SUBROUTINE NORML
C ESTABLISH SURFACE NORMAL FOR EACH PLATE SURFACE
C SURFACE NORMALS DIRECTED TOWARD COCKPIT INTERIOR
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     0,8)
      COMMON/VERT/XV(200),YV(200),ZV(200),NVR(100,8)
```

```
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     O0),CE(10),RC(10)
      COMMON/PILOT/XO,YO,ZO
      DO 10 I=1,ND
      NK=NV(I)
      DO 5 K=1,NK
      KV=NVR(I,K)
      PXV(I,K)=XV(KV)
      PYV(I,K)=YV(KV)
      PZV(I,K)=ZV(KV)
    5 CONTINUE
      K=2
    7 A1=PXV(I,K)-PXV(I,1)
      A2=PXV(I,K+1)-PXV(I,1)
      B1=PYV(I,K)-PYV(I,1)
      B2=PYV(I,K+1)-PYV(I,1)
      C1=PZV(I,K)-PZV(I,1)
      C2=PZV(I,K+1)-PZV(I,1)
      P1=SQRT(A1**2+B1**2+C1**2)
      P2=SQRT(A2**2+B2**2+C2**2)
      A=(A1*A2+B1*B2+C1*C2)/(P1*P2)
      IF(ABS(A).LT.1.) GO TO 9
      K=K+1
      IF(K.EQ.NK) GO TO 10
      GO TO 7
    9 AN=ACOS(A)
      R=1./(P1*P2*SIN(AN))
      AXN(I)=-(B1*C2-C1*B2)*R
      AYN(I)=+(A1*C2-C1*A2)*R
      AZN(I)=-(A1*B2-A2*B1)*R
   10 CONTINUE
      RETURN
      END
      SUBROUTINE FLEG
C CRAFT POSITION IN SCENE
C CRAFT ORIENTATION, DIRECTIONAL COSINES OF Y-AXIS AND Z-AXIS OF CRAFT I
C SCENE SPACE, Y-AXIS DIRECTED BACKWARDS ALONG LONGITUDINAL AXIS, Z-AXIS
C TOWARD VERTICAL
      COMMON/SC/XL,YL,ZL,AL,BL,CL,AAL,BBL,CCL
C CRAFT POSITION AND ORIENTATION IN SCENE
      READ(2,999)
  999 FORMAT()
      READ(2,1004)XL,YL,ZL,AL,BL,CL,AAL,BBL,CCL
 1004 FORMAT(2X,3(F10.4,2X)/2X,3(F10.4,2X)/2X,3(F10.4,2X))
      WRITE(3,1005)
 1005 FORMAT(2X,'POSITION'/4X,'X-POS',4X,'Y-POS',4X,'Z-POS')
      WRITE(3,1006)XL,YL,ZL,AL,BL,CL,AAL,BBL,CCL
 1006 FORMAT(4X,3(F10.4,2X)/4X,3(F7.4,2X)/4X,3(F7.4,2X))
      RETURN
      END
      SUBROUTINE SLIGP
      COMMON/GT/X,Y,Z
      COMMON/PILOT/XO,YO,ZO
      DATA DE/2./
      DATA AP/1H-/
      XOO=XO
      READ(2,1001)NDP
      WRITE(3,1001)NDP
```

```
1001 FORMAT(2X,I3)
     DO 10 I=1,NDP
     READ(2,1002)X,Y,Z
1002 FORMAT(3(2X,F10.4))
     WRITE(3,1000)I,X,Y,Z
1000 FORMAT(1H ,'LG=',I5,2X,'XL=',F10.4,2X,'YL=',F10.4,2X,'ZL=',F10.4)
     XO=XOO-3.
     DO 7 J=1,2
     XO=XO+DE
     WRITE(3,1003)XO,YO,ZO
1003 FORMAT(2X,"PILOT-EYE POSITION",3(2X,F10.4))
     CALL STPS
     CALL PRNT
   7 CONTINUE
     WRITE(3,1004)(AP,K=1,80)
1004 FORMAT(2X,80A1)
  10 CONTINUE
     RETURN
     END
     SUBROUTINE STPS
C COMPUTES AND STORES STATIC ANALYSIS OF LIGHT SOURCE REFLECTIONS
     COMMON/LIGHT/XL,YL,ZL
     COMMON/SC/XS,YS,ZS,AS,BS,CS,AAS,BBS,CCS
     COMMON/GT/XG,YG,ZG
     COMMON/FP/NSL,XP,YP,ZP,TP
     X=XS
     Y=YS
     Z=ZS
     A1=AS
     B1=BS
     C1=CS
     AA1=AAS
     BB1=BBS
     CC1=CCS
     VC=SQRT(B1**2+C1**2)
     CALL MROTX(B1/VC,C1/VC,AA1,BB1,CC1)
     CALL MROTZ(VC,A1,AA1,BB1,CC1)
     XL=XG
     YL=YG
     ZL=ZG
     CALL MTRNL(-X,-Y,-Z,XL,YL,ZL)
     CALL MROTX(B1/VC,C1/VC,XL,YL,ZL)
     CALL MROTZ(VC,A1,XL,YL,ZL)
     CALL MROTY(CC1,AA1,XL,YL,ZL)
     CALL COMPO(NSL,XP,YP,ZP,TP)
     CALL COMPL
     RETURN
     END
     SUBROUTINE PRNT
C PRINTS OUT LIGHT SOURCE DATA, DIRECT VIEW AND REFLECTION POINTS
     COMMON/LIGHT/XL,YL,ZL
     COMMON/FP/NSP,XP,YP,ZP,TP
     COMMON/FY/NSL,IS(10),XS(10),YS(10),ZS(10),IR(10),XR(10),YR(10),ZR(
    010),TR(10)
     WRITE(3,1000)XL,YL,ZL
1000 FORMAT(1H ,2X,'LIGHT SOURCE'/2X,'XL=',F10.4,2X,'YL=',F10.4,2X,'ZL=
    0',F10.4)
     IF(NSP.EQ.0)GOTO 5
     WRITE(3,1001)NSP,XP,YP,ZP,TP
```

```
 1001 FORMAT(1H ,2X,'DIRECT VIEW'/2X,I3,2X,4(3X,F10.4))
    5 CONTINUE
      IF(NSL.EQ.0)RETURN
      DO 6 I=1,NSL
    6 WRITE(3,1002)IS(I),XS(I),YS(I),ZS(I),IR(I),XR(I),YR(I),ZR(I),TR(I)
 1002 FORMAT(1H ,2X,'REFLECTION POINT'/(2X,2(I2,2X,3(F10.4,2X)),F10.4))
      RETURN
      END
      SUBROUTINE COMPO(NSL,XP,YP,ZP,TP)
C COMPUTES INTERCEPTION POINT OF STRAIGHT LINE RAY BETWEEN PILOT AND SOU
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10C
     O,8)
      COMMON/LIGHT/XL,YL,ZL
      COMMON/PILOT/XO,YO,ZO
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      NSL=C
      TP=1.
      XS=XC
      YS=YC
      ZS=ZC
      R=SQRT((XL-XO)**2+(YL-YO)**2+(ZL-ZO)**2)
      AS=(XL-XO)/R
      BS=(YL-YO)/R
      CS=(ZL-ZO)/R
      DO 1C IS=1,ND
      ISK=0
      IF(IS.LE.NP)CALL INTEC(ISK,IS,XP,YP,ZP)
      IF(IS.EQ.NA)CALL INTEC(ISK,IS,XP,YP,ZP)
      IF(IS.GT.NP)CALL INTCY(ISK,IS,XP,YP,ZP)
      IF(ISK.GT.0)GOTO 20
   1C CONTINUE
      RETURN
   20 CONTINUE
      IF(IS.LE.NC)RETURN
      IF(IS.EQ.NA)GOTO 30
      NSL=ISK
      CALL COMP(ANG,RT,TT)
      TP=TP*TT
      RETURN
   30 CONTINUE
      CALL COMP(ANG,RT,TT)
      TP=TP*TT
      GO TO 10
      END
      SUBROUTINE COMPL
C COMPUTE PRIMARY REFLECTION POINTS FOR SINGLE SOURCE OF LIGHT
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     O,8)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     O0),CE(10),RC(10)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/LIGHT/XL,YL,ZL
      COMMON/COFF/NN,AN(10),SS(10),NS,XRR(10),YRR(10),ZRR(10)
      COMMON/FY/NSL,ISX(10),XSX(10),YSX(10),ZSX(10),IRX(10),XRX(10),YRX(
     O10),ZRX(10),TRX(10)
      NSL=C
      NSS=NC+1
      DO 20 IS=NSS,ND
```

```
      IF(IS.LE.NP)GOTO 30
      IF(IS.GT.NP)GOTO 40
      GO TO 20
   30 CONTINUE
      AC=AXN(IS)
      BC=AYN(IS)
      CC=AZN(IS)
      XS=PXV(IS,1)
      YS=PYV(IS,1)
      ZS=PZV(IS,1)
      ISK=0
      CALL INTPL(ISK,IS)
      IF(ISK.EQ.0)GOTO 20
      CALL COMP(ANG,R,TT)
      DO 32 I=1,NP
      ISK=0
      IF(I.EQ.IS)GOTO 32
      IF(I.LE.NP)CALL INTEC(ISK,I,XR,YR,ZR)
      IF(I.GT.NP)CALL INTCY(ISK,I,XR,YR,ZR)
      IF(ISK.LE.0)GOTO 32
      IF(I.LE.NC)GOTO 20
      IF(I.EQ.NA)GOTO 36
      RX=AS*AC+BS*BC+CS*CC
      AS=AS-2.*RX*AC
      BS=BS-2.*RX*BC
      CS=CS-2.*RX*CC
      CALL COMP(ANG,RT,TT)
      T=R*TT
      NSL=NSL+1
      WRITE(3,1001)NSL,IS,XS,YS,ZS,I,XR,YR,ZR,T
 1001 FORMAT(2X,I5,2X,I3,2X,3(F10.4,2X),2X,I3,2X,4(F10.4,2X))
      ISX(NSL)=IS
      XSX(NSL)=XS
      YSX(NSL)=YS
      ZSX(NSL)=ZS
      IRX(NSL)=I
      XRX(NSL)=XR
      YRX(NSL)=YR
      ZRX(NSL)=ZR
      TRX(NSL)=T
      GO TO 20
   36 CONTINUE
      CALL COMP(ANG,RT,TT)
      R=R*TT
   32 CONTINUE
      GO TO 20
   40 CONTINUE
      DO 411 IC=1,NCY
      KP=NSC(IC)
      DO 411 KC=1,KP
      IF(NSP(IC,KC).EQ.IS)GOTO 42
      GO TO 411
   42 CONTINUE
      CALL INTCL(IC)
      IF(NS.GT.0)CALL INTS(IC,IS)
      IF(NS.EQ.0)GOTO 20
      DO 44 IK=1,NS
      XS=XRR(IK)
      YS=YRR(IK)
```

```
      ZS=ZKR(IK)
      RL=SQRT((XS-XL)**2+(YS-YL)**2+(ZS-ZL)**2)
      AS=(XL-XS)/RL
      BS=(YL-YS)/RL
      CS=(ZL-ZS)/RL
      RO=(XS-XC(IC))*AE(IC)+(YS-YC(IC))*BE(IC)+(ZS-ZC(IC))*CE(IC)
      AC=(XC(IC)-XS+RO*AE(IC))/RC(IC)
      BC=(YC(IC)-YS+RO*BE(IC))/RC(IC)
      CC=(ZC(IC)-ZS+RC*CE(IC))/RC(IC)
      CALL COMP(ANG,R,TT)
      DO 43 I=1,ND
      ISK=C
      IF(I.EQ.IS)GOTO 43
      IF(I.LE.NP)CALL INTEC(ISK,I,XR,YR,ZR)
      IF(I.GT.NP)CALL INTCY(ISK,I,XR,YR,ZR)
      IF(ISK.LE.0)GOTO 43
   45 CONTINUE
      IF(I.LE.NC)GOTO 44
      IF(I.EQ.NA)GOTO 46
      RX=AS*AC+BS*BC+CS*CC
      AS=AS-2.*RX*AC
      BS=BS-2.*RX*BC
      CS=CS-2.*RX*CC
      CALL COMP(ANG,RT,TT)
      T=R*TT
      NSL=NSL+1
      WRITE(3,1001)NSL,IS,XS,YS,ZS,I,XR,YR,ZR,T
      GO TO 44
   46 CONTINUE
      CALL COMP(ANG,RT,TT)
      R=R*TT
   43 CONTINUE
   44 CONTINUE
      GO TO 20
  411 CONTINUE
   20 CONTINUE
      RETURN
      END
      SUBROUTINE INTPL(ISK,IS)
C COMPUTES PRIMARY REFLECTION POINT OF LIGHT GIVEN POSITION WITH PLANE G
C VERTEX AND SURFACE NORMAL AND POSITION OF VIEWER
C DETERMINES IF RAY STRIKES CONVEX SURFACE
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     Q,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/LIGHT/XL,YL,ZL
      COMMON/PILOT/XO,YO,ZO
      QL=AC*(XL-XS)+BC*(YL-YS)+CC*(ZL-ZS)
      QO=AC*(XO-XS)+BC*(YO-YS)+CC*(ZO-ZS)
      ALF=QL/QO
      IF(ALF.LT.O.)RETURN
C LIGHT SOURCE AND PILOT ON SAME SIDE OF PANEL
      RLO=SQRT((XL-XO)**2+(YL-YO)**2+(ZL-ZO)**2)
      ALO=(XO-XL)/RLO
      BLO=(YO-YL)/RLO
      CLO=(ZO-ZL)/RLO
      AV=ALF*RLO/(1.+ALF)
      XE=XL+ALO*AV
      YE=YL+BLO*AV
```

```
      ZE=ZL+CLO*AV
      RE=AC*(XE-XS)+BC*(YE-YS)+CC*(ZE-ZS)
      XS=XE-AC*RE
      YS=YE-BC*RE
      ZS=ZE-CC*RE
      RL=SQRT((XS-XL)**2+(YS-YL)**2+(ZS-ZL)**2)
      AS=(XL-XS)/RL
      BS=(YL-YS)/RL
      CS=(ZL-ZS)/RL
      IN=NV(IS)
      DO 10 I=1,IN
      IC=I+1
      IF(I.EQ.IN)IC=1
      A1=PXV(IS,I)-XO
      B1=PYV(IS,I)-YO
      C1=PZV(IS,I)-ZO
      A2=PXV(IS,IC)-XO
      B2=PYV(IS,IC)-YO
      C2=PZV(IS,IC)-ZO
      P1=XS-XO
      P2=YS-YO
      P3=ZS-ZO
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.LT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      RETURN
      END
      SUBROUTINE INTCL(IC)
C DETERMINE CYLINDRICAL REFLECTION POINTS
      COMMON/LIGHT/XLL,YLL,ZLL
      COMMON/PILOT/XOO,YOO,ZOO
      COMMON/COFF/NN,AN(10),CS(10),NS,XRR(10),YRR(10),ZRR(10)
      COMMON/PLAC/XL,YL,ZL,XO,YO,ZO
      DATA NN/4/
      XL=XLL
      YL=YLL
      ZL=ZLL
      CALL TRANC(IC,XL,YL,ZL)
      XO=XOO
      YO=YOO
      ZO=ZOO
      CALL TRANC(IC,XO,YO,ZO)
      ROL=SQRT((XL-XO)**2+(YL-YO)**2+(ZL-ZO)**2)
      BOL=(YO-YL)/ROL
      AN(1)=(XO**2+ZO**2)**2-XO**2-ZO**2
      AN(2)=-2.*(XO*XL+ZO*ZL-XO**2-ZO**2)
      AN(3)=-(XO**2+XL**2+ZO**2+ZL**2-4.*XO*XL-4.*ZO*ZL+2.*(XO**2+ZO**2)
     Q*(XL**2+ZL**2))
      AN(4)=-2.*(XO*XL+ZO*ZL-XL**2-ZL**2)
      AN(5)=(XL**2+ZL**2)**2-XL**2-ZL**2
      CALL SPOLY
      NS=0
      DO 10 I=1,NN
      AF=ROL/(CS(I)+1.)
      RE=SQRT((XO+CS(I)*XL)**2+(ZO+CS(I)*ZL)**2)
      AE=(XO+CS(I)*XL)/RE
```

```
      CE=(ZO+CS(I)*ZL)/RE
      YE=YL+AF*BOL
      XR=AE
      YR=YE
      ZR=CE
      CALL SOLN(IC,XR,YR,ZR)
      XR=-AE
      YR=YE
      ZR=-CE
      CALL SOLN(IC,XR,YR,ZP)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE SOLN(IC,XR,YR,ZR)
      COMMON/COFF/NN,AN(10),CS(10),NS,XRR(10),YRR(10),ZRR(10)
      COMMON/PLAC/XL,YL,ZL,XO,YO,ZO
      RL=SQRT((XR-XL)**2+(YR-YL)**2+(ZR-ZL)**2)
      RO=SQRT((XR-XO)**2+(YR-YO)**2+(ZR-ZO)**2)
      QL=(1.-(XR*XL+ZR*ZL))/RL
      QO=(1.-(XR*XO+ZR*ZO))/RO
      IF(QL/QO.LT.O.)RETURN
      Q=QL+QO
      IF(Q.EQ.O.)RETURN
      IF(ABS((QL-QO)/Q).GT..01)RETURN
      NS=NS+1
      CALL INVC(IC,XR,YR,ZR)
      XRR(NS)=XR
      YRR(NS)=YR
      ZRR(NS)=ZR
      RETURN
      END
      SUBROUTINE MTRNL(XT,YT,ZT,X,Y,Z)
C TRANSLATION BY POSITIVE SCALARS
      X=X+XT
      Y=Y+YT
      Z=Z+ZT
      RETURN
      END
      SUBROUTINE MROTX(A,B,X,Y,Z)
C ROTATION ABOUT POSITIVE X-AXIS OF Y-AXIS IN POSITIVE DIRECTION
      AX=A
      BX=-B
      YV=AX*Y-BX*Z
      ZV=BX*Y+AX*Z
      Y=YV
      Z=ZV
      RETURN
      END
      SUBROUTINE MROTY(A,B,X,Y,Z)
C ROTATION ABOUT POSITIVE Y-AXIS OF Z-AXIS IN CLOCKWISE DIRECTION
      AY=A
      BY=-B
      XV=AY*X+BY*Z
      ZV=-BY*X+AY*Z
      X=XV
      Z=ZV
      RETURN
      END
      SUBROUTINE MROTZ(A,B,X,Y,Z)
```

```
C ROTATION ABOUT POSITIVE Z-AXIS OF Y-AXIS IN CLOCKWISE DIRECTION
      AZ=A
      BZ=B
      XV=AZ*X-BZ*Y
      YV=BZ*X+AZ*Y
      X=XV
      Y=YV
      RETURN
      END
      SUBROUTINE MSCAL(A,X,Y,Z)
C MAGNIFICATION BY POSITIVE SCALARS
      X=A*X
      Y=A*Y
      Z=A*Z
      RETURN
      END
      SUBROUTINE TRANC(IC,X,Y,Z)
C TRANSFER INTO CYLINDRICAL SOLUTION SPACE
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AC(10),BC(1
     00),CC(10),RC(10)
      CALL MTRNL(-XC(IC),-YC(IC),-ZC(IC),X,Y,Z)
      VC=SQRT(BC(IC)**2+CC(IC)**2)
      CALL MROTX(BC(IC)/VC,CC(IC)/VC,X,Y,Z)
      CALL MROTZ(VC,AC(IC),X,Y,Z)
      CALL MSCAL(1./RC(IC),X,Y,Z)
      RETURN
      END
      SUBROUTINE INVC(IC,X,Y,Z)
C INVERSE TRANSFORM FROM CYLINDRICAL SOLUTION SPACE
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AC(10),BC(1
     00),CC(10),RC(10)
      CALL MSCAL(RC(IC),X,Y,Z)
      VC=SQRT(BC(IC)**2+CC(IC)**2)
      CALL MROTZ(VC,-AC(IC),X,Y,Z)
      CALL MROTX(BC(IC)/VC,-CC(IC)/VC,X,Y,Z)
      CALL MTRNL(XC(IC),YC(IC),ZC(IC),X,Y,Z)
      RETURN
      END
      SUBROUTINE SPOLY
C REAL ROOTS TO POLYNOMIAL EQUATION USING SYNTHETIC DIVISION AND NEWTON'
C GRADIENT METHOD. ASSUMPTION THAT NO COMPLEX ROOTS PRESENT.
      COMMON/COFF/NN,AN(10),XS(10),NS,XRR(10),YRR(10),ZRR(10)
      DIMENSION BN(10)
      N=NN
      DO 30 I=1,NN
      IF(AN(1).EQ.0.)GOTO 41
      IF(AN(2).EQ.0.)GOTO 42
      XE=-AN(1)/AN(2)
      GO TO 5
   41 XE=0.
      GO TO 5
   42 IF(AN(3).EQ.0.)GOTO 43
      XE=SQRT(ABS(AN(1)/AN(3)))
      GO TO 5
   43 IF(AN(4).EQ.0.)GOTO 44
      XE=(-AN(1)/AN(4))**.33333
      GO TO 5
   44 XE=(ABS(AN(1)/AN(5)))**.25
    5 CONTINUE
```

```
      DO 20 J=1,100
      BN(N+1)=AN(N+1)
      C=0.
      DO 10 K=1,N
      L=N+1-K
      BN(L)=AN(L)+XE*BN(L+1)
      C=C*XE+BN(L+1)
   10 CONTINUE
      IF(C.EQ.0.)GOTO 40
      XR=XE-BN(1)/C
      GO TO 15
   40 CONTINUE
      XR=-10000.
   15 IF((XR+XE).EQ.0.)GOTO 20
      IF(ABS((XR-XE)/(XR+XE)).LT..001)GOTO 22
      XE=XR
   20 CONTINUE
   22 XS(I)=XE
      N=N-1
      AN(N+1)=BN(N+2)
      DO 30 J=1,N
      L=N+1-J
      AN(L)=BN(L+1)
   30 CONTINUE
      RETURN
      END
      SUBROUTINE INTS(IC,IS)
C DETERMINE WHETHER REFLECTED RAY POINT IS WITHIN ENCLOSED SURFACE ON
C CYLINDER
      COMMON/CAN/NT,NB,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(100
     0,8)
      COMMON/COFF/NN,AN(10),CS(10),NS,XS(10),YS(10),ZS(10)
      COMMON/PILOT/XO,YO,ZO
      XSS=XO
      YSS=YO
      ZSS=ZO
      CALL TRSCY(IC,XSS,YSS,ZSS)
      ISK=0
      DO 20 IK=1,NS
      XRR=XS(IK)
      YRR=YS(IK)
      ZRR=ZS(IK)
      CALL TRSCY(IC,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(IC,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      I=II+1
      IF(II.EQ.IN)I=1
      X2=PXV(IS,I)
      Y2=PYV(IS,I)
```

```
      Z2=PZV(IS,I)
      CALL TRSCY(IC,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.LT.0.)GOTO 20
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=ISK+1
      XS(ISK)=XS(IK)
      YS(ISK)=YS(IK)
      ZS(ISK)=ZS(IK)
   20 CONTINUE
      NS=ISK
      RETURN
      END
      SUBROUTINE INTCY(ISK,IS,XR,YR,ZR)
C COMPUTES INTERSECTION POINT OF LINE WITH CYLINDER
      COMMON/CAN/NT,NO,NC,NP,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10C
     0,8)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     00),CE(10),RC(10)
      COMMON/PILOT/XP,YP,ZP
C DETERMINE CYLINDERICAL SURFACE WHICH CONVEX SURFACE IS A PART OF
      DO 2 I=1,NCY
      KP=NSC(I)
      DO 2 K=1,KP
      IF(NSP(I,K).EQ.IS)GOTO 5
    2 CONTINUE
      RETURN
    5 CONTINUE
C DETERMINE INTERSECTION POINT
      XO=XC(I)
      YO=YC(I)
      ZO=ZC(I)
      RO=RC(I)
      AO=AE(I)
      BO=BE(I)
      CO=CE(I)
      ROS=SQRT((XS-XO)**2+(YS-YO)**2+(ZS-ZO)**2)
      AOO=(XS-XO)/ROS
      BOO=(YS-YO)/ROS
      COO=(ZS-ZO)/ROS
      A=AO*AS+BO*BS+CO*CS
      B=ROS*(AO*AOO+BO*BOO+CO*COO)
      A1=AS-A*((AO)**2)
      A2=BS-A*((BO)**2)
      A3=CS-A*((CO)**2)
      B1=AOO*ROS-B*((AO)**2)
      B2=BOO*ROS-B*((BO)**2)
      B3=COO*ROS-B*((CO)**2)
      A=A1**2+A2**2+A3**2
      B=A1*B1+A2*B2+A3*B3
```

```
      C=B1**2+B2**2+B3**2
      AB=-B/A
      BB=(SQRT(B**2-A*(C-RO**2)))/A
      RS=AB-BB
      IF(RS.LT.0.)RS=AB+BB
      XR=XS+AS*RS
      ZR=ZS+CS*RS
      YR=YS+BS*RS
      R=RS*(AO*AS+BO*BS+CO*CS)+ROS*(AO*AOO+BO*BOO+CO*COO)
      X1=XO+AO*R
      Y1=YO+BO*R
      Z1=ZO+CO*R
      AC=(X1-XR)/RO
      BC=(Y1-YR)/RO
      CC=(Z1-ZR)/RO
C DETERMINES WHETHER RAY STRIKES ENCLOSED SURFACE
      XSS=XP
      YSS=YP
      ZSS=ZP
      CALL TRSCY(I,XSS,YSS,ZSS)
      XRR=XR
      YRR=YR
      ZRR=ZR
      CALL TRSCY(I,XRR,YRR,ZRR)
      P1=XRR-XSS
      P2=YRR-YSS
      P3=ZRR-ZSS
      X1=PXV(IS,1)
      Y1=PYV(IS,1)
      Z1=PZV(IS,1)
      CALL TRSCY(I,X1,Y1,Z1)
      A1=X1-XSS
      B1=Y1-YSS
      C1=Z1-ZSS
      IN=NV(IS)
      DO 10 II=1,IN
      IC=II+1
      IF(II.EQ.IN)IC=1
      X2=PXV(IS,IC)
      Y2=PYV(IS,IC)
      Z2=PZV(IS,IC)
      CALL TRSCY(I,X2,Y2,Z2)
      A2=X2-XSS
      B2=Y2-YSS
      C2=Z2-ZSS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.LT.0.)RETURN
C RAY STRIKES SURFACE ON ENCLOSED SIDE OF SURFACE EDGE
      A1=A2
      B1=B2
      C1=C2
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      ISK=1
      RETURN
      END
      SUBROUTINE TRSCY(I,XR,YR,ZR)
C CONVERTS CYLINDRICAL COORDINATES INTO RECTANGULAR COORDINATES
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
```

```
     0O),CE(10),RC(10)
      CN=SQRT(1.-CE(I)**2)
      AN=-AE(I)*CE(I)/CN
      BN=-BE(I)*CE(I)/CN
      AP=BE(I)*CN-BN*CE(I)
      BP=-(AE(I)*CN-AN*CE(I))
      CP=AE(I)*BN-AN*BE(I)
      RO=AE(I)*(XR-XC(I))+BE(I)*(YR-YC(I))+CE(I)*(ZR-ZC(I))
      XX=XC(I)+AE(I)*RO
      YY=YC(I)+BE(I)*RO
      ZZ=ZC(I)+CE(I)*RO
      R=SQRT((XR-XX)**2+(YR-YY)**2+(ZR-ZZ)**2)
      AA=(XR-XX)/R
      BB=(YR-YY)/R
      CC=(ZR-ZZ)/R
      A=AN*AA+BN*BB+CN*CC
      IF(A.GT.1.)A=1.
      IF(A.LT.-1.)A=-1.
      ANG=ACOS(A)
      G=AP*AA+BP*BB+CP*CC
      IF(G.LT.0.)ANG=-ANG
      XR=ANG*RC(I)
      YR=RO
      ZR=R-RC(I)
      RETURN
      END
      SUBROUTINE INTEC(ISK,IS,XR,YR,ZR)
C DETERMINE IF RAY STRIKES CONVEX SURFACE
      COMMON/CAN/NT,NB,NC,NF,NA,ND,NV(100),PXV(100,8),PYV(100,8),PZV(10C
     O,8)
      COMMON/CYL/NCY,NSC(10),NSP(10,10),XC(10),YC(10),ZC(10),AE(10),BE(1
     0O),CE(10),RC(10)
      COMMON/NORM/AXN(100),AYN(100),AZN(100)
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
      CK=AXN(IS)*AS+AYN(IS)*BS+AZN(IS)*CS
      IF(CK.GE.0.)RETURN
C RAY STRIKES SURFACE IN OUTWARD DIRECTION
      I=1
      IF(XS.EQ.PXV(IS,I).AND.YS.EQ.PYV(IS,I).AND.ZS.EQ.PZV(IS,I))I=I+1
      S=(AXN(IS)*(PXV(IS,I)-XS)+AYN(IS)*(PYV(IS,I)-YS)+AZN(IS)*(PZV(IS,I
     O)-ZS))/CK
      XR=AS*S+XS
      YR=BS*S+YS
      ZR=CS*S+ZS
      IN=NV(IS)
      DO 10 I=1,IN
      IC=I+1
      IF(I.EQ.IN)IC=1
      A1=PXV(IS,I)-XS
      B1=PYV(IS,I)-YS
      C1=PZV(IS,I)-ZS
      A2=PXV(IS,IC)-XS
      B2=PYV(IS,IC)-YS
      C2=PZV(IS,IC)-ZS
      P1=XR-XS
      P2=YR-YS
      P3=ZR-ZS
      Q=P1*(B1*C2-B2*C1)-P2*(A1*C2-C1*A2)+P3*(A1*B2-B1*A2)
      IF(Q.LT.0.)RETURN
```

```
C RAY STRIKES SURFACE CN ENCLOSED SIDE OF SURFACE EDGE
   10 CONTINUE
C RAY STRIKES ENCLOSED SURFACE
      AC=-AXN(IS)
      BC=-AYN(IS)
      CC=-AZN(IS)
      ISK=1
      RETURN
      END
      SUBROUTINE COMP(ANG,RT,TT)
C COMPUTES INCIDENCE ANGLE, REFLECTANCE, AND TRANSMITTANCE
C NATURAL LIGHT, ADDITION OF POLARIZATION COMPONENTS IGNORED
      COMMON/LINE/AS,BS,CS,XS,YS,ZS,AC,BC,CC
C XN, INDEX OF REFRACTION, TX, INTERNAL TRANSNITTANCE
      DATA XN,TXX/1.5,.05/
      TT=0.
      A=AS*AC+BS*BC+CS*CC
      IF(A.LT.0.)A=-A
      IF(ABS(A).GT.1.)A=1.
      ANG=ACOS(A)
      ANGP= ASIN(SIN(ANG)/XN)
      CA=COS(ANG)
      SA=SIN(ANG)
      S1=SQRT(XN**2-SA**2)
      RO=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TO=(1.-RO)*CA/COS(ANGP)
      CA=COS(ANGP)
      SA=SIN(ANGP)
      TX=EXP(-TXX/CA)
      S1=SQRT(XN**2-SA**2)
      RI=(((CA-S1)/(CA+S1))**2+((CA*(XN**2)-S1)/(CA*(XN**2)+S1))**2)/2.
      TI=(1.-RI)*CA/COS(ANG)
      TT=TO*TI*TX/(1.-(RI*TX)**2)
      RT=RO+RI*TT*TX
      RETURN
      END
C COBRA MOCKUP FLAT PLATE CANOPY DATA, MODEL 209 AH-1S HELICOPTER
C NO. VERTICES, AND SURFACES--BODY, CONSTRAINT, AND TRANSPARENT
  190     5    83    90     0    90
C NO. VERTICES PER SURFACE
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     6     6     4     4     4
    4     6     6     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     4     4
    4     4     4     4     4     4     5     5
    5     5
C SURFACE VERTICES IN ROTATIONAL ORDER- ALL 1ST VERTICES, ALL 2ND, ETC.
    4     4     1     5     3    12     9     9
   13    15    17    16    15    22    19    22
   24    19    25    29    29    38    35    42
   39    48    43    49    52    53    56    60
   57    64    61    65    72    72    71    76
   73    80    77    81    81    82    83    89
```

89	90	91	97	97	102	99	103
103	104	105	111	111	112	113	119
123	121	121	127	127	132	129	139
135	137	140	143	145	145	143	154
153	153	151	159	163	167	171	180
181	190						
3	8	5	1	7	11	10	10
14	18	21	20	19	19	22	25
23	24	26	34	30	37	36	41
40	47	44	50	51	54	55	59
58	63	62	66	67	71	70	75
74	79	78	85	82	83	84	93
90	91	92	102	98	101	100	107
104	105	106	115	112	113	114	122
124	120	125	130	131	133	133	140
138	141	141	147	146	149	144	151
.154	157	152	160	164	168	172	179
182	189						
2	7	8	2	6	10	11	14
10	22	22	21	20	26	23	28
28	27	27	33	31	36	37	40
41	46	45	51	50	55	54	58
59	62	63	67	66	68	69	74
75	78	79	88	86	87	88	96
94	95	96	99	99	100	101	110
108	109	110	118	116	117	118	126
120	124	126	134	132	129	134	136
142	142	137	150	150	148	148	155
158	156	156	161	165	169	173	178
183	188						
1	3	4	6	2	9	12	13
9	19	18	17	16	25	24	23
27	26	28	32	32	35	38	39
42	45	46	52	49	56	53	57
60	61	64	72	65	67	68	73
76	77	80	84	85	86	87	92
93	94	95	98	102	99	102	106
107	108	109	114	115	116	117	123
119	125	122	131	128	128	130	135
139	138	136	146	149	144	147	158
157	152	155	162	165	170	174	177
184	187						
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	31	33	0	0	0
0	44	47	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	175	176
185	186						
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	30	34	0	0	0
0	43	48	0	0	0	0	0

```
C X-POSITION ALL VERTICES
   -6.       -6.        6.        6.      -12.      -12.       12.       12.
  -17.       17.       13.      -13.      -15.       15.        2.        2.
   -2.       -2.        2.        2.       -2.       -2.       -2.        2.
   -2.        2.        2.       -2.      -15.5      15.5      15.5       6.25
   -6.25    -15.5     -10.907    -6.25     -4.969    -9.969     6.25     10.875
   10.093     5.312   -16.       16.       15.313     5.375    -5.812   -16.093
  -10.5     -10.5     -10.5     -10.5      10.5      10.5      10.5      10.5
   15.5      14.938    15.063    15.063   -15.5     -14.906   -14.875   -14.875
  -15.125    15.125    15.425    15.875    15.75    -15.75    -15.875   -15.4
   13.5      15.032    15.032    13.5     -13.407   -15.032   -15.032   -13.407
   13.       11.375    11.375    13.       11.75     10.125    10.125    11.75
  -11.157   -12.782   -12.782   -11.157   -10.375   -12.      -12.      -10.375
  -13.       13.       13.       13.      -13.      -13.       11.75     10.125
   10.125    11.75     13.344    11.719    11.719    13.344   -10.375   -12.
  -12.      -10.375   -11.282   -13.282   -13.282   -11.282    12.282    10.782
   10.782    12.282    17.062    15.562    17.25     15.75    -11.75    -13.25
  -13.282   -11.782   -15.562   -16.782   -16.688   -17.25     12.282    12.282
   12.282    12.282   -12.282   -12.282   -12.282   -12.282    12.657    10.657
   10.657    12.657    14.375    12.375    12.375    14.375   -11.282   -13.282
  -13.25    -11.282   -12.375   -14.375   -14.375   -12.375   -11.157    11.375
   10.125   -10.375   -10.375    10.094    10.657   -11.282   -12.375    11.719
   12.375   -11.313    13.5      15.032    17.062    13.625    12.157   -13.407
  -15.063   -16.782   -13.25    -12.657    13.75     17.25     16.262    16.063
   14.375   -13.282   -16.688   -16.688   -15.907   -14.375      .         .
C Y-POSITION ALL VERTICES
   22.788    22.788    22.788    22.788    55.288    55.288    55.288    55.288
   57.288    57.288    55.288    55.288    57.288    57.288    57.788    57.788
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```
  57.788    57.788    67.288    67.288    67.288    67.288    73.188    73.188
  67.288    67.288    73.188    73.188    92.788    92.788    95.288   101.788
 101.788    95.288    98.405   101.788   101.843    99.843   101.788    98.249
 99.78     101.874   110.788   110.788   110.25    110.062   110.28    110.71
 104.788   110.663   109.788   107.788   104.788   110.663   109.788   107.788
 133.038   154.125   141.655   135.594   133.038   154.030   141.5     135.468
  59.158    59.158   152.908   154.658   151.408   151.408   154.658   152.908
  57.562    59.975    61.475    59.062    57.343    59.475    61.475    58.843
  57.187    57.187    57.187    57.187    72.218    72.218    72.218    72.218
  56.537    56.537    56.537    56.537    72.218    72.218    72.218    72.218
  71.375    71.468    72.218    73.218    73.218    72.218    72.218    72.218
  72.218    72.218   110.218   110.218   110.218   110.218    72.218    72.218
  72.218    72.218   110.218   110.218   110.218   110.218   108.03    108.03
 110.468   110.468    98.437    98.437   101.155   101.155   106.312   106.312
 109.156   109.156    98.437    98.218   101.343   101.155   108.28    108.28
 110.218   110.218   108.28    108.28    110.218   108.28    108.28    108.28
 108.28    108.28    153.28    153.28    153.28    153.28    108.312   108.312
 108.312   108.312   110.655   110.655   110.655   110.655    56.937    57.187
  71.468    71.375    73.218    73.218   106.28    106.312   110.655   110.218
 153.28    153.125    59.062    61.375    98.437   106.03     73.218    58.843
  61.312    98.218   106.312    73.25    108.937   101.155   154.28    155.218
 152.28    109.156   101.343   155.375   156.875   153.25        .         .
C Z-POSITION ALL VERTICES
  66.446    45.446    45.446    66.446    71.288    45.446    45.446    71.288
  61.946    61.946    78.446    78.446    45.446    45.446    68.946    64.946
  64.946    66.946    78.446    74.446    74.446    78.446    78.446    78.446
  71.446    71.446    71.446    71.446    69.446    69.446    75.446    64.946
  84.946    75.446    79.718    79.946    83.343    83.750    79.946    79.593
 83.687     83.348    79.576    79.576    79.436    85.562    56.437    76.437
  77.576    80.076    83.576    83.576    77.576    80.076    83.576    83.576
  83.076    87.562    87.187    84.437    83.076    87.625    87.187    84.468
  70.821    70.821    89.321    94.696   104.946   104.946    94.696    89.321
  77.156    66.275    66.275    77.156    77.25     66.       66.       77.25
  76.25     76.25     74.25     74.25     92.187    92.187    90.187    90.187
  76.093    76.093    74.093    74.093    92.562    92.562    90.562    90.562
  91.312    91.625    92.187    92.812    92.562    92.187    92.187    92.187
  90.187    90.187   105.968   105.968   103.968   103.968    92.562    92.562
  90.562    90.562   105.968   105.968   103.968   103.968   105.812   105.812
 105.812   105.812    75.237    75.237    76.087    76.087   104.932   104.937
 105.812   105.812    75.237    75.087    75.637    76.087   103.812   105.812
 105.812   103.812   103.812   105.812   105.812   105.812   105.812   105.812
 103.812   103.812   105.906   105.906   103.906   103.906   105.718   105.718
 103.718   103.718   106.      106.      104.      104.       76.093    76.25
  91.625    91.312    92.562    92.812   105.812   105.718   106.      105.968
 105.906   105.718    75.156    66.375    75.437   102.937    90.187    75.25
  66.062    75.187   102.937    90.437   103.906    76.187    88.343    93.75
 104.062   103.812    75.937    88.812    93.906   104.125       .         .
C CYLINDRICAL DATA
   0
C PILOT-EYE POSITION
 0.        138.968   95.406
C MOCKUP POSITION AND ORIENTATION ON TEST FLOOR
 0.            24.75          -30.586
     0.            -1.             0.
 0.            0.             1.
  28
 48.           -100.44        36.
 60.           -88.44         36.
 36.           -76.44         12.
```

72.	-40.44	48.
84.	-40.44	24.
36.	-28.44	12.
48.	-28.44	24.
36.	-4.43	36.
72.	7.57	48.
12.	19.57	12.
36.	31.57	48.
60.	31.57	24.
12.	43.57	48.
24.	43.57	36.
60.	43.57	48.
60.	-52.	12.
36.	-40.4	12.
36.	-28.4	12.
24.	7.56	12.
36.	7.56	36.
60.	43.57	24.
48.	-88.4	48.
72.	-64.4	48.
72.	-4.43	48.
12.	31.56	24.
84.	-100.4	12.
60.	-52.4	48.
72.	-16.4	36.